Integrated Urban Stormwater Master Planning

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Abstract

Urban stormwater management agencies are increasingly being called upon to address water quality and natural resources issues in addition to their traditional focus on flood conveyance. In response to this, stormwater drainage master plans have been increasingly addressing stormwater quality and, in limited cases, natural resources and habitat. This paper will describe some of the problems with traditional stormwater master planning approaches, including those where water quality and natural resources have been included as "add-ons," and the urban stormwater problems we are now trying to address which have resulted from these approaches. A framework for how communities can develop integrated stormwater master plans that address multiple objectives, as increasingly mandated by public concern as well as by regulations, will be presented. Given that the tools available for master planning are not equivalent in their numerical evaluations, new procedures and project approaches are required. Especially important is how the hydrology/hydraulic methods are performed, including both flood evaluations and evaluation of the smaller channel-forming storms.

Communities are often not institutionally organized to address multiple objectives. Master planning has traditionally been led and performed by engineers trained in hydrology and hydraulics, and they are usually in different departments from those who are responsible for other environmental aspects of the drainage system. This paper will focus on the technical, institutional, and process-oriented aspects of how master planning can be improved. Several case studies from the Pacific Northwest of the United States will be discussed.

Introduction

The purpose of this paper is to discuss some of the attributes of urban stormwater master planning and how those master plans can be improved to more fully address issues besides conveyance capacity and flood control. Stormwater master plans go by a number of names, including storm drain master plans, stormwater infrastructure plans, and urban catchment management plans. These plans are usually very focused on flood control and, until just recently, address water quality minimally. This paper will discuss some of the attributes of traditional urban stormwater master planning and its results, regulatory programs (which in the US and New Zealand are requiring adifferent approach), how integrated master planning can be accomplished, and institutional barriers which often prevent integrated master planning from being accomplished. In this paper, an Integrated Stormwater Master Plan is an infrastructure and management plan that not only addresses flood control and property protection issues, but also considers stream stability and habitat, along with water quality and aesthetics.

Urban Stormwater Drainage Problems

It has long been recognized that in urban areas, unplanned stormwater management systems result in damage to property and sometimes people. As it will be well demonstrated by other papers in these proceedings, urbanization of watersheds and the resulting impervious areas also cause changes to the hydrology and water quality of receiving waters which ultimately result in other impacts to aquatic life and humans. Even some of our measures to control impacts can have unplanned detrimental effects. Especially sensitive to these changes are stream systems and coastal embayments that are not well flushed. Almost always there are also direct impacts to stream riparian areas which also increase these changes through canopy removal and channel modifications.

Urbanization usually includes impervious areas directly connected to efficient stormwater conveyance systems (including roof drains and driveways connected to streets and curbs to inlets to pipes) which then are discharged to streams directly or through engineered channels. This has resulted in stormwater being conveyed as fast as possible to receiving waters (and away from properties). Increasingly, it is being recognized that because stormwater is drained to streams in this manner, small storm hydrological changes that result in increased runoff flows can significantly increase the frequency and duration of elevated flows. This energy change within the normal wetted channel often results in channel cutting, widening, and/or sedimentation, which in turn can cause severe habitat and water quality degradation (MacRae 1996; Sovern and Washington, 1996). Often to "fix" these channel problems, streams are enclosed, hardened, and/or straightened. Even without considering the water quality of stormwater, our stormwater systems are severely impacted from a physical habitat standpoint, including habitat loss, higher velocities, and temperature changes. Figure 1 shows an example of how stream runoff can change with urbanization, including much higher and peaky flows as well as increased volumes of runoff.

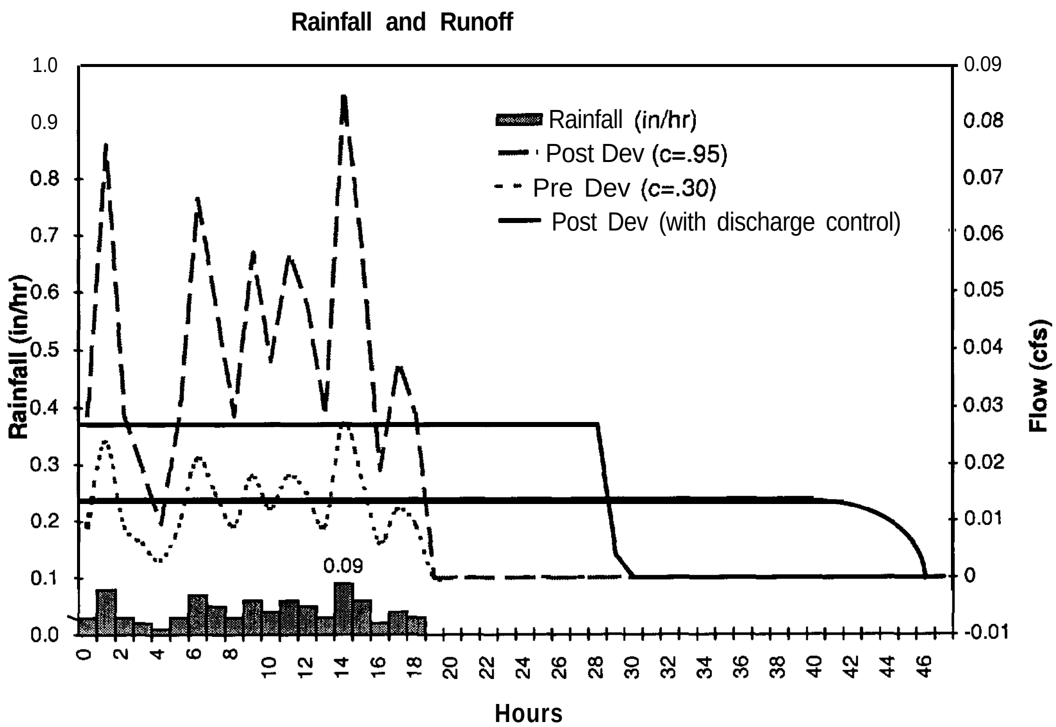
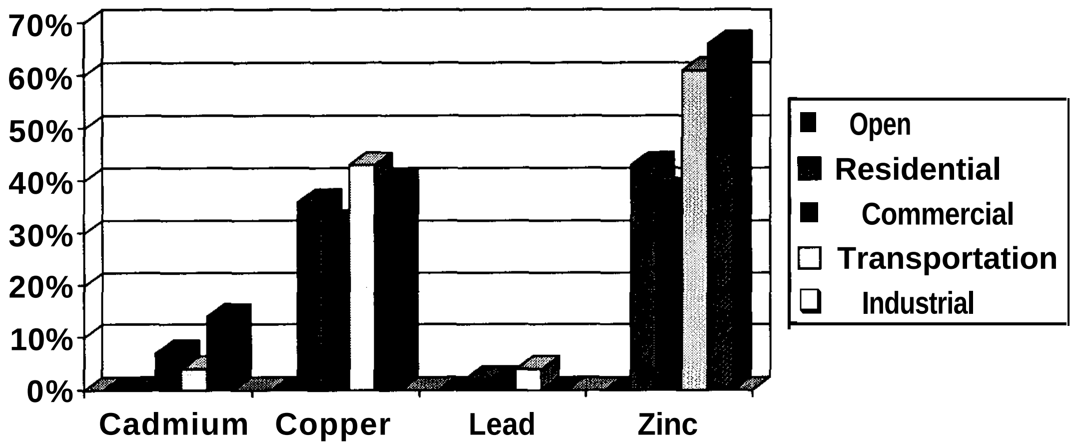


Figure 1. Example Schematic of Changing Rainfall/Runoff Relationships with Development.

With urbanization also comes a dramatic change in water quality. Urban stormwater systems are the efficient conveyance system of urban pollutants, both those discharged during storm events and those occurring during dry-weather discharges. There are numerous ways that pollutants enter stormwater from those in the rainfall itself to commonly thought of sources such as street dirt and car drippings. Stormwater often exceeds US EPA water quality criteria. Figure 2 is a graph of the frequency that stormwater runoff from identified land uses in Oregon exceed US EPA acute dissolved metals water quality criteria in runoff from identified land uses (Strecker et al., 1997). It should be noted that most of this runoff was measured in pipes, while the criteria are meant to apply to receiving waters. A data set of flow-weighted composite samples (representing average storm concentrations) from over 40 land use stations from various areas of the Willamette Valley was utilized to develop the information displayed in the figure. The stations included an open land use station in an urban area (Forest Park in Portland) for comparison. Note that dissolved copper and zinc in developed land uses exceeded criteria for 30 to 65% of the storm events. Similar findings have been found in other programs, including the San Francisco Bay area programs (Cooke and Lee, 1993).



Based upon Oregon NPDES Stormwater Monitoring Data Compiled by ACWA. Developed areas: 27 to 67 storm events; Open space: 9 storm events

Figure 2. Frequency that Flow-weighted Composite Urban Stormwater Runoff Samples Metals Concentrations Exceeded US EPAs Acute Criteria for Aquatic Life.

The water quality impacts together with the physical hydrology changes described above have caused our urban stream systems to become severely degraded. Our traditional systems have not protected the resources nearly as well as they have protected property. As many have now recognized, at about 10 to 25% imperviousness, the health of the aquatic system is severely degraded (May et al., 1997; Schueler, 1994). In many cases because of the longer-term channel stresses, property has been damaged as well, including under cutting of headwalls, etc. The plans typically only identified solutions that solved large flooding problems, sometimes just temporally until what has been considered “maintenance” problems such as head wall failures, occur.

Environmental Concerns and Regulatory Requirements

In the US, Congress has recognized that urban stormwater plays a major role in affecting receiving waters when it mandated in the revised Clean Water Act that urban stormwater water quality be addressed through a permitting (consent) program. New Zealand has similar requirements through its Resources Management Act of 1991. Both these programs are still evolving. The stormwater permit program in the US specifically requires that larger cities (over 100,000) and soon smaller cities address stormwater quality issues as they conduct flood control projects. New Zealand’s program also requires that municipalities obtain consents for stormwater discharges.

Under the overall program, one area that has been slow to change is how urban stormwater master plans are developed and implemented. Although there are requirements to consider water quality in conducting flood control efforts, for a number of reasons (including institutional inertia) agencies have been somewhat slow in actually giving water quality and habitat protection equal weight with flood control in master planning. Some of this is due to the fact that stormwater master plans are typically the responsibility of engineers who are experienced in hydraulics, but that often lack experience and knowledge in other aspects of environmental stormwater management. To be fair, engineers have been told to plan for managing stormwater based upon land-use zoning that was selected without considering stormwater issues. Another major issue is the resources allocated to conduct integrated planning efforts which are more expensive; often agencies do not recognize the value of better up-front planning compared to capital and maintenance costs.

Increasingly though, the public has started to demand that more environmentally sound and/or aesthetically pleasing stormwater management approaches be utilized. For example, with the endangered species act (ESA) listings and proposed listings of salmon and trout species in the US Pacific Northwest, many neighborhood organizations are pressuring municipal agencies to change their stormwater management approaches. Some of these efforts are having more success than the regulatory programs.

Stormwater Management Agency Functions

Understanding a stormwater management agency's function and history is important to understanding its approach to stormwater management. Stormwater management agencies typically fulfill the following roles:

1. Stormwater System Maintenance
2. Development Standard
3. Stormwater Master Planning
4. CIP Design and Construction
5. Funding-Utilities/System Development Charges
6. Stormwater System Permitting and Environmental Impact Minimization
7. Education

The last two elements are the most recent. Many agencies began by responding to emergencies and problems, and were then tasked to develop onsite design conveyance standards. Stormwater master plans for the most par-t were developed in response to problems that arose after watersheds were developing with little or no stormwater planning. They also were typically focused on just flood control and property protection. Most often they focused on the piped systems and road culverts. Often creeks away from culverts were not evaluated unless there had been a particular problem identified. In the US, the Federal Emergency Management Agency (FEMA) had separately developed flood plain maps for larger systems, which communities relied upon for protecting structures from larger river and stream flooding. This was done to meet requirements for participation in FEMA's flood insurance program. Therefore, flood plains and the creeks themselves have not been a focus of master plan (e.g., creek sections were typically not evaluated to a great extent).

Stormwater Drainage Master Plan Goals and Results

The traditional purposes of the Stormwater Drainage Master Plan were to:

- Guide a city's stormwater drainage system capital improvement project (CIP) program. (e.g., identify, select, cost, and prioritize stormwater system construction projects.)
- Establish a maintenance program for the stormwater system (recommended stormwater system maintenance practices and frequencies)
- Establish onsite conveyance requirements (design standards for level of peak flow conveyance by an engineered stormwater system and, sometimes, requirements for street conveyance of stormwater beyond the onsite requirements)

Master plans seldom included requirements for development with regard to stormwater system impacts (e.g., downstream flow and/or water quality impacts). Master plans were sometimes utilized to assess potential future problems as well as to fix existing problems. Often systems were evaluated under current conditions and future planned zoning to be able to assess costs to current rate/tax payers or new developments. Because master plans were not usually completed prior to some significant level of development, attributing these costs was important to the development community as well as to the residents.

The traditional approach to stormwater master planning has been to focus on hydrology and hydraulics of the existing stormwater systems, and proposed larger trunk systems to determine whether there is enough capacity. This is usually is accomplished by the following steps:

- Route a designated large storm through system, assume worst case conditions (saturated, etc.) and determine capacity deficiencies

- Develop an enlarged (or more efficient) system to handle larger flows or, when necessary, reduce peak flows by detention (if the cost of detention is less than a conveyance upgrade)

- Sometimes consider water quality as a “add-on” (e.g., if detention is required, claim a water quality benefit)

This approach has certainly significantly reduced property damage (sometimes only for short-term), but has led to more damage in streams. The damage has been a result of a significant increase and duration in small storm runoff flows. The result of not planning for this increased energy, which is primarily contained within the stream channel, has often been an increase in maintenance and property damage. For example, channel cutting that occurs upstream of culverts often causes headwall and culvert failures. In other areas where channel cut sediments settle out (often in over-designed or poorly designed culverts), areas are filled in with sediments. When this occurs (especially in a culvert), it can lead to flooding. These problems (headwall failures, culverts filled in, etc.) are often called maintenance issues, when they are in fact really failures of the master plan to adequately address stream impacts of development.

Typically smaller urban stormwater systems (e.g., 10 to 50 acre catchments) are dominated from a flooding standpoint by shorter-duration, more-intense storms (thunderstorms), whereas, the larger urban watersheds are often impacted by larger, but less-intense storms of longer duration. Master plans typically utilize a single large design storm event based upon a rainfall depth (mm of rain over a watershed) for a specified duration and return period. This depth is then assigned a conservative shape such as the SCS type IA shape shown in Figure 3). The storm shown is the 25-year, 24-hour storm depth for Eugene, Oregon, with the SCS distribution applied to it. As an example of how overly conservative the peak of

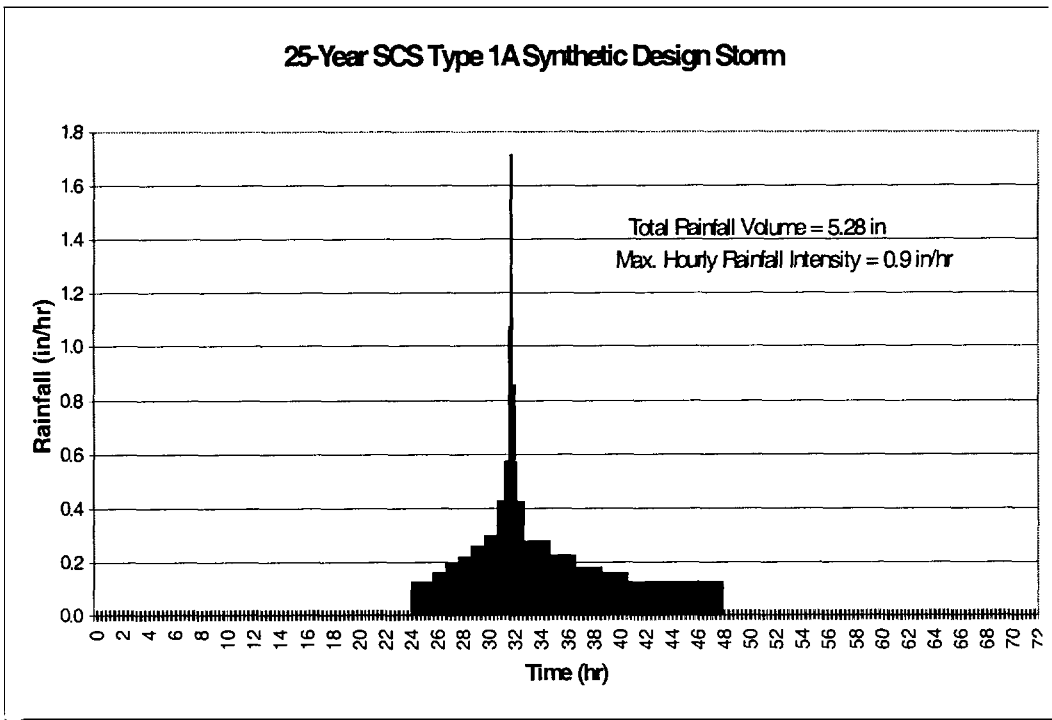


Figure 3. 25-Year, 24-Hour SCS Type 1A Synthetic Design Storm for Eugene, Oregon.

the “design” hydrograph is, Figure 4 shows an actual 25-year storm hydrograph (based upon analysis of the Eugene Airport rain gage). This storm was confirmed by long-term simulation modeling to have caused approximately the 25-year return-period flows in the larger stormwater systems in the city. In reality, the 25-year return-period storm depth seldom if ever arrives with the peaky “shape” given it in master plans.

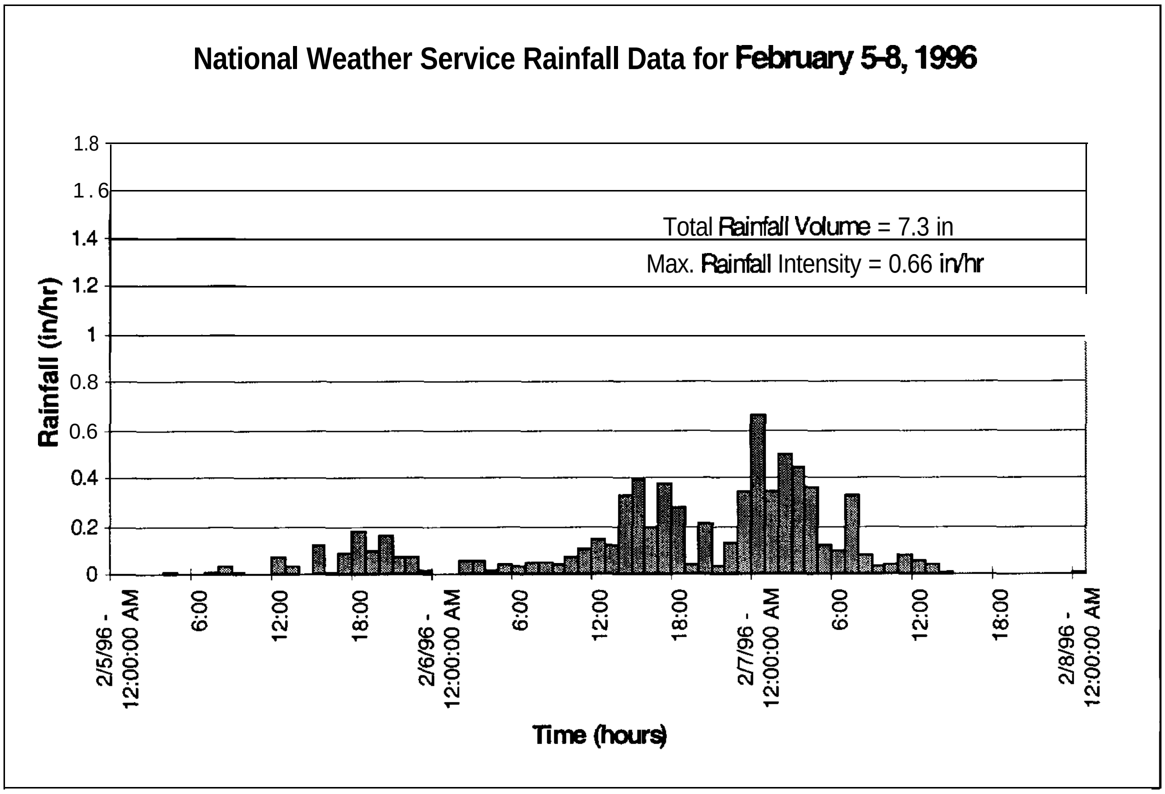


Figure 4. Rainfall Event that was Considered to Cause the Approximately 25-Year Return Period Peak Runoff Flows in Eugene, Oregon.

Many have justified this shape as being one that will also allow flood control effects of smaller thunderstorms on the smaller stormwater systems to be adequately evaluated. When the peak is modeled in this fashion on a larger watershed during an already large rainfall, the peak may greatly affect the larger system design. This conservative design approach we believe has led many communities to determine that streams are undersized and must be widened, channeled, and/or piped.

Of course in communities where there is the potential for combined phenomenon to cause severe flooding (e.g., snowmelt and frozen ground combined with a hard rain), there may be good reason to over size facilities. However, in most cases, it may be more appropriate to utilize methods that account for this and to strive to preserve open channels in more natural ways (e.g., larger stream buffers) to the extent possible.

Another assumption that is often made is that the watershed is saturated before the design storm arrives. This assumption is made to be “conservative.” However, it results in an uneven level of conservatism. This assumption would tend to lead to the most over-designed conveyance systems in the least paved areas. That is, the saturation assumption would tend to make systems most over-designed in low-density, single-family areas vs. less over-designed in the downtown core area. The point here is that the levels of over-design are not consistent, nor targeted to the areas where the greatest level of protection is desired (highest property value).

Finally, water quality, and sometimes habitat, is only now being considered in master planning. This is most often accomplished by adding water quality to a detention feature or specifically selecting and locating several demonstration water quality projects. Some communities have chosen to not emphasize habitat by engineering their streams with the purpose of providing flood conveyance as recreational amenities. The Denver area is a good example of this type of design. In arid areas, where streams are seasonal or even just storm driven, this may be a good choice for communities. However, some communities are considering the value of seasonal streams play for downstream resources from a biological and water quality perspective. For example in Eugene, Oregon, the city has determined that seasonal streams contain a rich fauna of aquatic invertebrates (WCC, 1995) which likely would benefit the health of downstream systems.

There are a number of reasons why the above approaches have continued to be employed. First, planning that considers multiple objectives is much more difficult to accomplish, from the technical approaches, due to the need to involve more parties in decision making. The traditional technical approach described above is straightforward, while design of more natural systems is not (e.g., pipe flow equations are much easier to utilize then open channel flow in natural streams). In addition, there are many more people to involve in making decisions than dealing only with engineered physical structures within the stormwater system. Second, most municipalities are not organized well for the purpose of urban watershed planning. The City of Portland, Oregon (which has been very progressive in many ways) still has four separate departments (all in one bureau) that do: 1) facilities planning (stormwater system master planning), 2) site stormwater standards, 3) stormwater quality (permit compliance), and 4) watershed management. Each of these groups has developed its own plans and programs that have understandably not been very well-coordinated or integrated. Finally, and probably most important, is that integrated planning studies cost significantly more (on the order of 2 to 4 times as much).

Integrated Storm Drainage Master Plans - Approach

The new approach to stormwater master plans is the integration of flood control, water quality, natural resources, and aesthetics of stormwater systems. This approach requires significantly more effort and should be thought of as one that will entail adaptive management. That is, the master plan must include components that allow for changing conditions as development occurs and the downstream systems react.

In completing a stormwater master plan, it is difficult to achieve “maximums” of flood control, water quality, natural aquatic habitat, and aesthetics. It is somewhat analogous to the rule that it is hard to get a cheap price, good service, and high quality. It is our belief that one of the problems with master plans has been a lack of recognition that streams will change and that the plans should be developed to manage change in a positive fashion.

One of the keys to successful integrated master planning is that the planning approach places the proper emphasis on the technical and decision-making processes employed. As mentioned above, master plans typically have been driven by the hydrologic/hydraulic modeling of large storm(s) and usually begin with model data collection and analysis. Figure 5 presents a suggested flow diagram for an alternative way of sequencing the development of a master plan. It begins by conducting an inventory of all aspects of the stormwater system, including all attributes related to the multiple objectives mentioned above. The approach suggests utilizing multi-disciplinary teams to review conditions in the field to look for opportunities for meeting objectives, as well as reviewing existing and suspected future problems. Next, before any modeling is done, the project team and decision-makers should utilize the collected information to develop goals and objectives for the plan. Then additional technical analyses, including where and what type of detailed hydrologic/hydraulic modeling is appropriate, can be decided upon based upon these objectives. We have found this approach sharpens the focus of modeling so that the model is not “driving” the master plan into solutions that focus primarily on conveyance upgrades.

In developing an integrated master plan, it is generally understood that the right mix of multi-disciplinary technical specialists should be involved. In addition, it is important to involve the “right” decision-makers and stakeholders early in the process. It is also important to agree up-front upon the decision-making process that will be utilized. We have found that utilizing an agreed upon set of factors to evaluate, select, and rank projects is very useful not only for guiding the process more objectively, but also to serve as a history of why certain projects were recommended and why others were not. This is very useful for future decision-makers for two reasons. First, when questioned by others, there will be

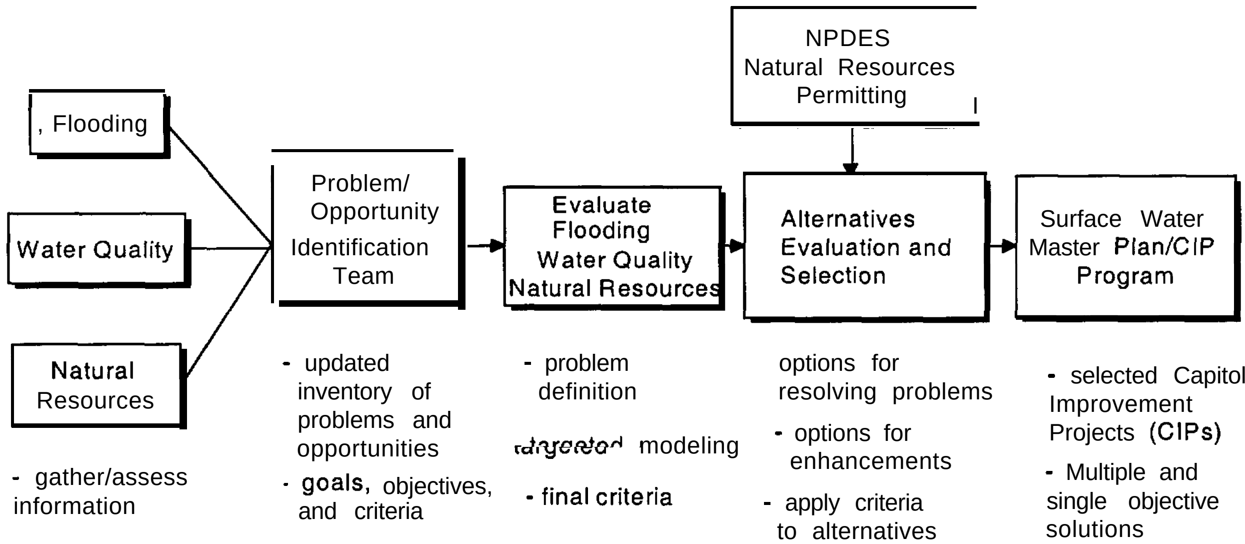


Figure 5. Suggested Integrated Stormwater Master Plan Project Approach.

some backing for why certain decisions were made. Second, as conditions that affect the factors change, selection of projects can also change in a logical fashion.

The approach we recommend is to evaluate solutions that are primarily single objective rather than those that are multiple objective. That is, a two-stage decision process is employed to make sure that good single-objective solutions are not ignored because of the multi-objective nature of the factors. The factors employed include:

- Addresses flooding problems
- Addresses water quality pollutants of concern
- Meets community amenity objectives
- Habitat value
- Life-cycle costs
- Meets regulatory requirements
- Implementability
- Reliability/sustainability
- Other environmental impacts
- Equability

Integrated Storm Drainage Master Plans - Hydrology

Integrated stormwater master planning includes evaluating and considering smaller storm hydrological impacts. Figure 6 presents a storm-depth frequency curve for Portland, Oregon. The figure demonstrates that storms of a depth of 1.5 inches and less dominate both the number of storms (more than 95%) and the volume of runoff (over 90%). It is the smaller storms of about 0.3 to 0.8 inches in depth that change the most in their characteristics. In natural areas of the Northwest, these often did not result in appreciable runoff or resulted only in slightly elevated flows for a long duration. However, after urbanization, these storms are causing severe and rapid changes in flow levels with each storm. This kind of analysis can be used to assist decision makers in deciding what level of water quantity and water quality control is going to be the most cost-effective in reducing the impacts of urbanization.

The best hydrologic and hydraulic modeling approach for assessing and designing stormwater systems is likely the use of continuous simulation models using long-term rainfall records to evaluate a system under a wide range of varying hydrologic conditions. However, this is quite expensive. One of the approaches that we have been taking is to utilize long-term simulations of stormwater systems to select design storms. We believe that this improves the consistency in providing design storms that are closer to the level of protection that is being "advertised," without having to run long-term simulations. This approach involves using real rainfall data with continuous simulation models (e.g., SWMM) to define the resulting return frequency of runoff peaks in various parts of the stormwater system. Then, real storms are selected

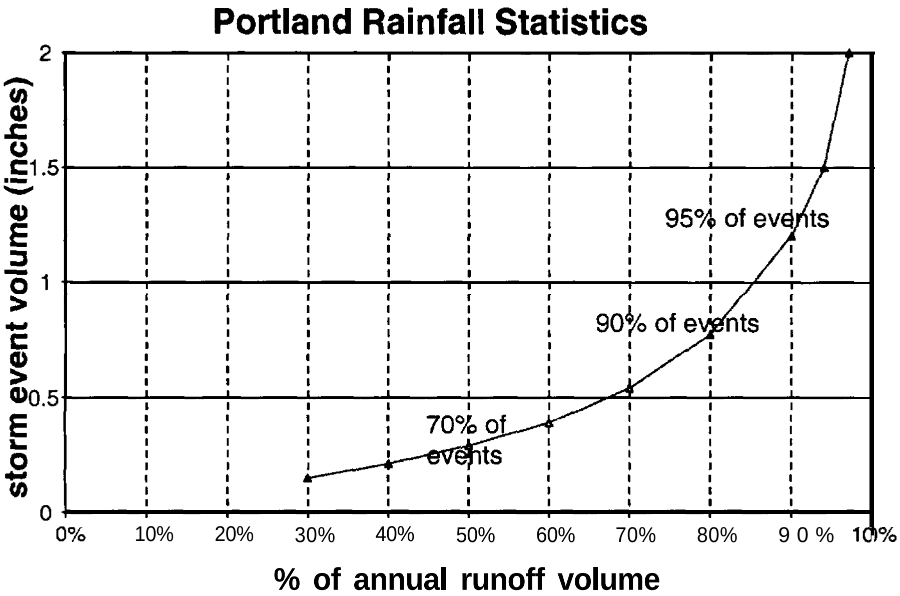


Figure 6. Cumulative Storm Event Rainfall Depth Analysis for Portland, OR Airport

that resulted in the return period of interest (using a partial duration frequency analysis). These “real” storms are then utilized to design the system. Figure 7 presents an example of partial-duration frequency evaluation of peak flows in one of the basins in the Eugene, Oregon area. From this frequency distribution, the storm that was closest to the intended design level (25-year) was selected for design analysis of the system. Figure 8 shows a similar analysis for another basin in Eugene, along with the design flows from an earlier master plan (which utilized the traditional SCS storm method with saturated conditions).

What Figure 8 demonstrates is that in this basin, the more traditional approach would have resulted in what is likely a significant over-design of the system. In most basins, this was found to be the case. However, there were several basins that were close and a few where the real storm approach resulted in larger designs. Figure 9 and 10 compare the resulting designs in the Flat Creek basin in Eugene. Note that the real storm approach resulted in fewer and smaller projects in this basin. This means that the city can utilize more of its scarce resources to complete other types of multi-objective projects. One of the advantages of the use of real storms is that the concept is very easy to communicate to citizens. In addition, the city has found that some of its channels are over-designed compared to the stated level of protection, and that they may be able to relax vegetation maintenance requirements to allow for more natural channels. Overall, the city is finding that allocating sufficient resources to conduct an integrated plan will likely lead to a more cost-effective program overall, in terms of multiple benefits.

Integrated Storm Drainage Master Plans – Water Quality

There are a number of stormwater quality models and approaches (Donigian and Huber, 1991). Some are quite simple and straightforward, while others are much more complex. In general, water quality models currently cannot accurately predict how pollutants get into stormwater. Although some researchers have made great strides in establishing sources of pollutants in the urban environment (Pitt, 1993), there still are numerous pollutant sources that are not fully understood. Most models rely on either some land-use-based concentrations to drive water quality predictions or they use a build-up/wash-off function to describe pollutant concentrations (Donigian and Huber, 1991).

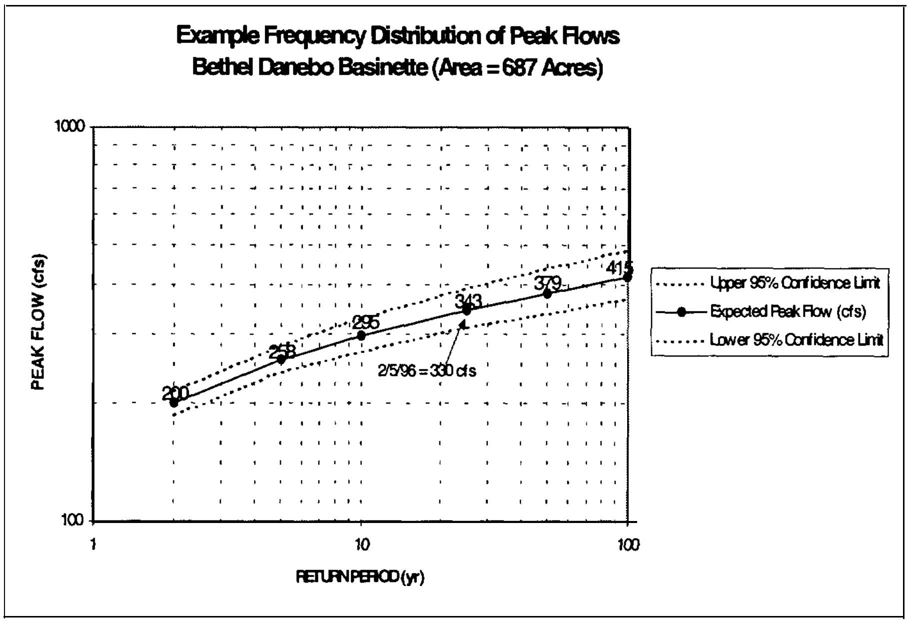


Figure 7. Example Frequency Distribution of Peak Flows in Eugene, OR.

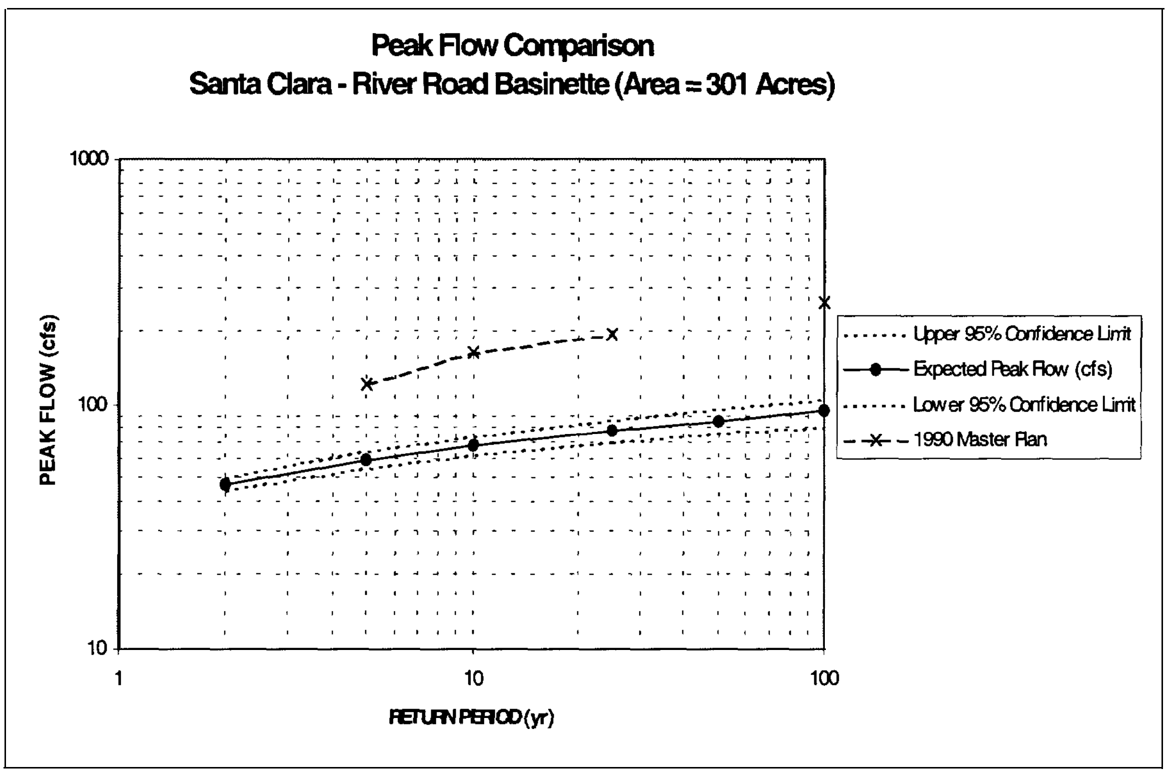


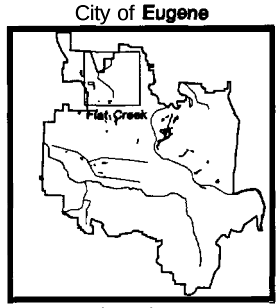
Figure 8. Peak Flow Comparison in Urban Runoff from Eugene, OR.

Flat Creek Drainage System

Capital Improvements Proposed in 1990 Master Plan

Using lo-year SCS Synthetic Design Storm

City of **Eugene**



Enlarged Area

Open Channel

Pipe or Cukert

Transition Between Section

	CIP Proposed in 1990 Master Plan	Cost
1	30" RCCP replaced by 4'x3' RCBC	$27,300
2	open channel replaced by 2-36" RCCP	$175,400
3	30" RCCP replaced by 2-3'x3' RCBC	$31,800
4	existing channel expansion	$9,100
5	existing channel expansion	$3,900
6	existing channel expansion	$21,000
7	3-43"x27" CMP replaced by 2-6'x3' RCBC	$87,100
8	2-36" RCCP replaced by 2-4'x3' RCBC	$81,100
9	58"x36" and 24" CMP replaced by 2-5'x3' RCBC	$117,100
	Total	$553,800

Figure 7

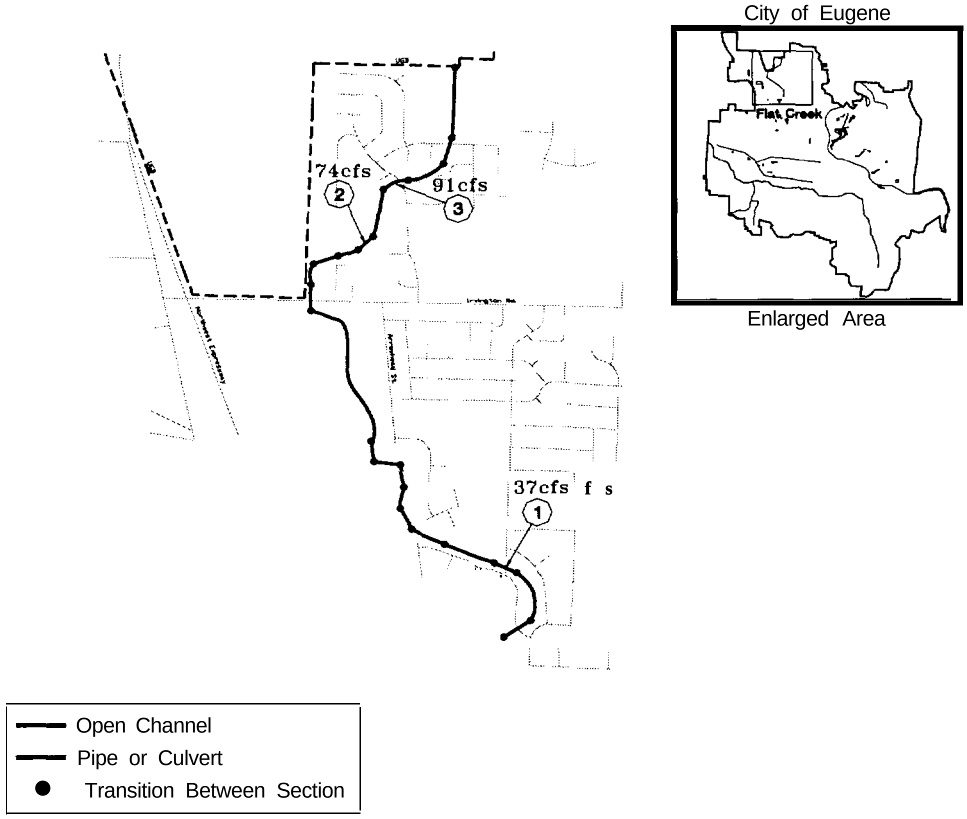
Figure 9. Proposed Conveyance System Improvements Utilizing the SCS Type **1A** Synthetic Design Storm and Assuming Saturated Conditions.

The build-up/wash-off of suspended solids (TSS) is modeled and then TSS concentrations are utilized to predict other concentrations for such parameters as phosphorus and heavy metals. The first problem with this approach is that it assumes that the build-up/wash-off of TSS is much greater than any other source pathway. This has not been found to be the case (Pitt, 1993). When build-up based/wash-off models are calibrated to real data, the build-up/wash-off function must be set to be much larger than it really is in order to match actual data. When a source control such as street sweeping is applied, the model will then significantly overestimate its effectiveness no matter what the assumed street sweepingefficiency is. This may explain why street sweeping has seldom if ever been found to be as effective as predicted. The second problem with these models is the assumption that other constituent concentrations can be related

Flat Creek Drainage System

Capital Improvements Proposed by Woodward-Clyde

Using lo-year Design Storm of November 23, 1960



	CIP Proposed by WCI	
①	30" RCCP replaced by 36" RCCP	$11,200
②	2-36" RCCP Replaced by 2-4'x3' RCBC	$85,200
③	2-36" RCCP Replaced by 2-4'x3' RCBC	$81,100
	Total	$178,000

Figure 6

Figure 10. Proposed Conveyance System Projects Utilizing Selected Real Storms for Design.

to TSS concentrations. Strecker (1997) presented data on TSS vs. metals relationships for Portland, Oregon stormwater data. Although the correlations were significant (r^2 of .3 to .4), we do not believe that they are high enough to be utilized without some stochastic functions employed. We believe that many master plans have utilized over-complicated stormwater pollutant load models that have not represented the actual processes well and have not resulted in better plans compared to their cost.

Based upon the above, we believe that the proper approach to assessing water quality in master planning is to utilize land-use based, simpler spreadsheet-based statistical models for water quality assessments and planning. If hydrologic/hydraulic based solutions are being contemplated then more complex models (such as SWMM) can evaluate detention times might be called for.

There have been a number of attempts to develop a better understanding of how stormwater quality BMPs work and why (Strecker, 1992; Brown and Schueler, 1997). However, what we know about the effectiveness of stormwater best management practices in improving water quality and ultimately aquatic health has been questioned with good reason (Strecker 1994; Urbonas 1995; Maxted and Shaver, 1996). Some of the questions arise from the actual studies and how they have not been completed as to be very useful in assessing effectiveness. In addition, there have been suggestions that pollutant removal efficiencies may not be the best way to assess effectiveness (irreducible concentrations, etc.).

Finally, there have been some studies that have shown that downstream of some BMPs (e.g., detention systems), aquatic invertebrate populations are no different from systems that do not have such in-stream ponds (Maxted and Shaver, 1996).

What we know is the application of BMPs is an evolving science and that the exact cause and effect relationships are not well known. However, we do know that BMPs have been effective at reducing concentrations. In cases where there has been no downstream improvement in aquatic invertebrate health from BMPs, we should ascertain what the limiting factors are and whether the BMP was able to mitigate some if not all of them before we dismiss a BMP. In addition, we need to understand whether other attributes of the BMP may be contributing to downstream problems such as demonstrated downstream temperature impacts (Galli, 1991) of on-line ponds, as well as the interruption of drift of aquatic invertebrates downstream. It is becoming increasingly clear that within-stream detention systems need to be very carefully evaluated before they are selected as BMPs. What we will need to do in master planning is to make good subjective decisions regarding the appropriate application of BMPs for water quality. We do not have the data and models to do otherwise.

Integrated Storm Drainage Master Plans – Stream Stability/Habitat

Unless a watershed has a great ability to infiltrate stormwater or evaporation is a viable technique, stream hydrology will change (increased runoff) with development. While there are some great techniques to reduce the changes (e.g., Prince Georges Department of Environmental Resources. 1997), in many cases these techniques will not be able to reduce the increased energy within a stream enough to stop channel cutting and downstream sedimentation from occurring. A technique that has been employed in an attempt to prevent downstream damage is the requirement that new development controls runoff from a one- or two-year event such that pre- and post- development peak flows for that event are equaled. MacRae (1996) has demonstrated that this approach may actually cause more problems then it solves. It usually leads to shifting over-bank flow energy to the wetted channel, further exacerbating channel down cutting. Figure 1 demonstrates this. Suppose that the peak **in** hour 14 was the one-year pre-development flow for this creek. Maintaining post-development flows to this level would significantly lengthen the time the creek is subject to this channel-forming flow condition, while reducing over-bank flows. Even setting post-development peak runoff rates to one-half pre-development, results in significant extended energy in the channel. One would likely have to set a requirement that the flow rate be one-fourth or one-fifth to have a positive effect. This would require very large detention areas.

In many, if not most cases, we believe that the master plan must include within-stream structures to assist it in changing with development (Sovern, 1996). That is, the plan must move beyond just getting runoff to a stream and making sure any culverts in the stream are “right-sized.” Master plans should include a component to design in-stream structures (habitat friendly ones, of course) and have an adaptive management program for them. This approach has been successfully applied to the Pipers Creek and Thorton Creek watersheds in Seattle, both heavily urbanized watersheds. What this can accomplish is much faster and more postive equilibrium for the stream system (e.g., the increased energy can be utilized to create deeper pools and increased spawning gravels in the pool tailway).

Integrated Storm Drainage Master Plans – Capital Improve Projects (CIPs)

The above integrated stormwater master planning elements will result in changing the traditional definition of what a CIP is. Traditionally it has been structural controls located within the municipally owned stormwater systems (e.g., the streets and street drainage structures and at creek crossings, etc.) Now CIPs can include property or property rights acquisition, buffer areas, protection and enhancement of natural resource sites and preservation of the open channel drainage system.

Integrated Storm Drainage Master Plans – Public vs. Private Solutions

Another element of master planning can include the evaluation of the trade-off of requiring private solutions (e.g., on-site design requirements) versus implementing public stormwater system measures. Figure 11 shows schematically that on a watershed basis, one could employ a combination of both to achieve the overall most cost-effective system. This can be addressed in modeling and cost-estimation for both approaches and then one or some combination employed.

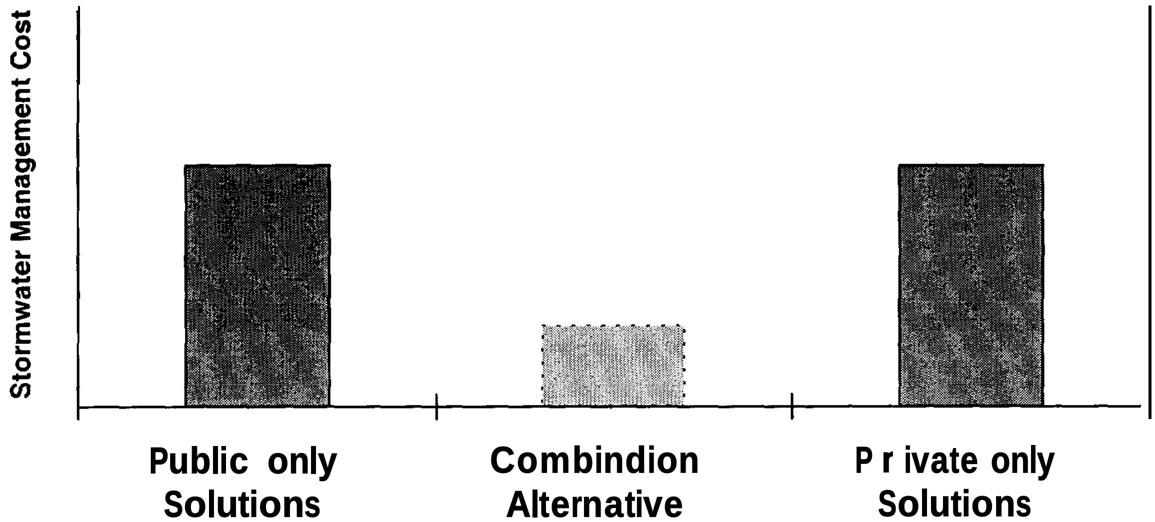


Figure 11. Conceptual Comparison between On-site Private Stormwater Solutions and Public Solutions.

Summary

In summary, urban stormwater management involves a complex set of phenomenon to manage and our stormwater science is lacking to support solely science-based decisions. Urban stormwater master planning needs to be conducted as an integrated planning and implementation process that considers water quality, habitat, and aesthetics along with urban flooding in order to meet increasing regulatory and environmental demands of the public. Typically, BMPs will only reduce the increase in small-storm hydrology that impacts physical stream habitat and stormwater pollutants; in-stream stability measures are needed as a part of master planning and urban system. Master planning and implementation needs to be thought of as an iterative process that will require adaptive management over time. A balanced approach that places the proper emphasis on problem definition, priority and goal setting, selection of measures/controls, participation by stakeholders, implementation, and monitoring/feedback/plan refinement is needed.

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